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EFFECTS OF FORGING REDUCTION ON 120-MM M256 TUBE MATERIAL

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The purpose of this effort was to investigate the effects of forging reduction on the resulting mechanical properties developed in gun tube forgings. Experimental forging was performed on a 120-mm gun tube preform in a GFM-55 rotary forging system, where the starting material was machined to a special configuration to provide a range of rotary forging reductions from 1:1 to 5:1. Both the test data and microstructural results of this study showed no significant effect of forging reduction on the resulting properties. These

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20. ABSTRACT (CONT'D)

results indicate that forging reduction has little or no effect on the mechanical properties of 120-mm gun tube material. However, the data indicate that the uniformity of properties over the range of forging reductions is due to the superior quality of the material. Electroslag remelted material used to produce 120-mm preforms appears to be capable of maintaining uniform mechanical properties over the range of reductions investigated. It is anticipated that steels produced without a secondary melting process will not maintain uniformity of properties over the same range of forging reductions. This same effort will be repeated on a material which does not experience a secondary melting process.

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INTRODUCTION

Variations in mechanical properties of heat treated gun tubes have historically been a concern in the production of reliable and acceptable gun tubes. Reasons for these variations include melting and forging practice, chemistry, heat treatment procedure, testing procedure, etc. Specifically, in this investigation the amount of forging reduction was examined to determine if it causes a spread in mechanical properties from the breech to the muzzle end of gun tubes. The objective was to show that the difference in forging reduction between the breech and muzzle ends accounts for the difference in mechanical properties from one end to the other.

PROCEDURE

An experimental forging was designed to cover a range of forging reductions as large as possible for this investigation. The starting material selected was a 120-mm M256 preform with excess test material which could be utilized for the experiment. The steel was produced by electroslag remelting (ESR) methods and press forged in an open die operation to its initial preform dimensions. The preform end to be rotary forged first was machined to a tapered section allowing for a range of forging reductions as it was forged into the muzzle end of a 120-mm M256 tube (Figure 1). The extra material in the preform was forged into extra muzzle length in the resulting forging. The forging reduction range selected was from 1:1 to 5:1, which was the practical limit of our rotary forging equipment. This forging reduction range on the GFM-55 rotary forge, combined with the open die press forging reduction from the starting ingot, gives a total forging reduction range from 3.36:1 to 16.90:1 as shown in Table I. Forging reduction is defined as the ratio of the cross-sectional area of the starting material to the cross-sectional area of the resulting forging. In the experiment, the cross-sectional area of the tapered section of the preform was computed at incremental locations along the length of the taper. Then the location of the material in the muzzle section of the resulting 120-mm forging was computed at these incremental locations (Table II). After forging, the tube was heat treated in a Selas heat treat system. This is a horizontal, continuous heat treat system used to thermally process all rotary forged production gun tubes. Standard heat treat parameters for the 120-mm M256 gun tube were used to heat treat this tube. Forging reduction ranges were sampled by cutting nine test discs at the locations specified in Table II and then machining them into test specimens as shown in Figure 2. Four tensile and four Charpy test specimens were evaluated from each test disc.

RESULTS AND DISCUSSION

Mechanical

The test specimens from the nine muzzle test discs as well as a standard breech end test disc were tested, and the results are given in Table III. The range shown for each of the mechanical properties indicates no significant variation in property levels along the entire length of the tube (see Figures 3 through 7). The results also show no upward or downward trend when comparing the mechanical properties obtained within the nine muzzle discs or from breech to muzzle ends.

Metallurgical

As-tested mechanical property samples from discs #2, #5, #7, and #9 were metallographically prepared and metallurgically examined to determine what effect forging had on the material's microstructural features. The samples were examined for general microstructure, nonmetallic inclusion content/morphology, macrostructure, and grain size. The samples selected spanned the full range of forging reductions. None of the corresponding mechanical properties of these samples displayed significant variations from disc to disc. This observation was further supported by the general lack of microstructural variations in the samples evaluated. All samples exhibited a fine-grained, tempered martensitic microstructure indicating successful heat treatment as seen in Figures 8 and 9. The "macrostructural" characterization showed a reasonably uniform structure (Figures 10a and 10b), suggesting very little chemical heterogeneity in this material.

The inclusions found in all samples were predominantly of an oxide type and were relatively small in size and distribution (see Figure 11). The "worst case" stringer-type inclusion found in any of the samples is identified by the arrow in Figure 11. This inclusion, magnified in Figure 12, was identified as a silicate. The lone microstructural variation found in these samples appeared in the grain size determinations. Table IV shows the average ASTM grain size for each disc.

The general trend of this data reveals that as forging reduction increases, grain size increases. (NOTE: As grain size increases, grain size number decreases.) This agrees well with the metallurgical theory that if all other variables for a material are comparable, the regions which experience the most mechanical working prior to heat treatment nucleate grains faster during heat treatment, and consequently, these grains can grow to a larger size.

SUMMARY AND CONCLUSION

All mechanical property values reported in this experiment showed good uniformity across the entire forging reduction range. The metallurgical analyses corroborated the mechanical property results. Metallographic samples obtained from each disc were prepared and examined and all displayed a uniform tempered martensitic microstructure. The material's macrostructural features were also uniform and showed no significant chemical inhomogeneity. Nonmetallic inclusion content/morphology was also uniform from disc to disc. The ASTM grain size was the lone material feature showing any variation. As stated previously, the grain size increased predictably as the forging reduction (or amount of mechanical working) increased. The varied grain sizes, however, did not appear to significantly affect the mechanical properties from disc to disc.

It should be noted that the material used in this experiment was a premium quality steel produced by consumable remelting methods. The general lack of sizeable nonmetallic inclusions in this material, especially malleable types (i.e., sulfides), and the relative absence of chemical segregation minimizes the probability that ductility-related mechanical properties (percent reduction in area (% RA) and percent elongation (% EL)) will be affected by varying forging reduction. This also tends to make this type of experiment more appropriate for showing forging reduction effects on strength and toughness. Because these properties were also uniform, it can be concluded that typical 120-mm M256 forging shows no significant mechanical property variations resulting from forging reduction variation over the range in this study.

Mechanical properties, especially ductility, tend to display less uniformity as the material displays increased structural and chemical inhomogeneity. Because the manufacturing method for the 155-mm and 105-mm preforms/forgings does not include a secondary melting process (i.e., ESR or vacuum arc remelting (VAR)), these materials inherently possess more material variation than the 120-mm material and would most likely show the effects of this variation in mechanical or physical property responses.

TABLE I. FORGING REDUCTIONS

(Cross-Sectional Areas Taken From Figure 1)

Ingot to Forging

$706.9 \text{ in.}^2/210.6 \text{ in.}^2 = 3.36:1$

Preform to Tube Forging

(Tapered Section of the Preform to Muzzle Diameter)

Minimum $31.5 \text{ in.}^2/31.5 \text{ in.}^2 = 1:1$

Maximum $158.6 \text{ in.}^2/31.5 \text{ in.}^2 = 5.03:1$

Total Forging Reduction

Minimum $3.36 \times 1 = 3.36:1$

Maximum $3.36 \times 5.03 = 16.90:1$

TABLE II. RELATIONSHIP BETWEEN PREFORM LOCATION, FORGING REDUCTIONS, AND CROSS-SECTIONAL AREA

(120-mm Tube Forging Muzzle End Cross-Sectional Area = 31.5 in.^{2})

Forging Reduction	Location (in.)	Preform Area (in.^{2})	Diameter (in.^{2})	Resulting Location in Tube* (in.)
1:1	0-6	31.5	7.95	0-6
1.5:1	8.5	47.3	9.12	9.11
2:1	10.7	63.0	10.16	12.96
2.5:1	12.7	78.8	11.10	17.45
3:1	14.6	94.5	11.97	22.53
3.5:1	16.3	110.3	12.78	28.14
4:1	17.9	126.0	13.55	34.26
4.5:1	19.5	141.8	14.27	40.79
5:1	20.9	157.5	14.95	47.64

*Measured from the muzzle end.

TABLE III. EXPERIMENTAL FORGING DATA

Test Disc	12 O'Clock				3 O'Clock	6 O'Clock				9 O'Clock
	Y.S.	T.S.	%RA	%EL	Charpy	Y.S.	T.S.	%RA	%EL	Charpy
1	157	167	57	16	59	155	166	57	16	57
2	A1)153 A2)155	164 165	54 56	14 15	B1)62 B2)57	C1)158 C2)155	167 165	55 53	15 14	D1)60 D2)57
3	A1)153 A2)152	163 163	57 54	17 14	B1)58 B2)59	C1)157 C2)156	167 166	50 54	14 14	D1)57 D2)53
4	A1)155 A2)153	165 164	55 54	15 14	B1)56 B2)52	C1)155 C2)155	165 166	53 53	14 14	D1)56 D2)54
5	A1)153 A2)153	164 164	56 56	16 16	B1)52 B2)53	C1)155 C2)155	165 166	57 52	17 14	D1)56 D2)52
6	A1)155 A2)155	165 165	57 54	16 14	B1)57 B2)56	C1)156 C2)157	166 168	54 56	14 16	D1)55 D2)50
7	A1)157 A2)155	166 166	57 56	16 16	B1)54 B2)50	C1)155 C2)155	165 165	55 57	15 16	D1)56 D2)52
8	A1)155 A2)155	165 166	57 57	16 16	B1)52 B2)51	C1)157 C2)157	167 168	54 53	14 14	D1)57 D2)49
9	A1)155 A2)155	165 165	60 57	17 16	B1)58 B2)53	C1)157 C2)155	168 167	55 59	15 16	D1)58 D2)56
Br End	158	169	56	15	56	158	168	53	14	54

Y.S. - Yield Strength
T.S. - Tensile Strength
A1,A2,B1,B2,C1,C2,D1,D2 - See Figure 2

TABLE IV. GRAIN SIZE COMPARISON

Disc #	Forging Reduction	Average ASTM Grain Size	Average Grain Area x 10^{-7} in.^{2}
2	1.5:1	8.9	3.3
5	3:1	8.4	4.7
7	4:1	8.4	4.7
9	5:1	7.7	7.6

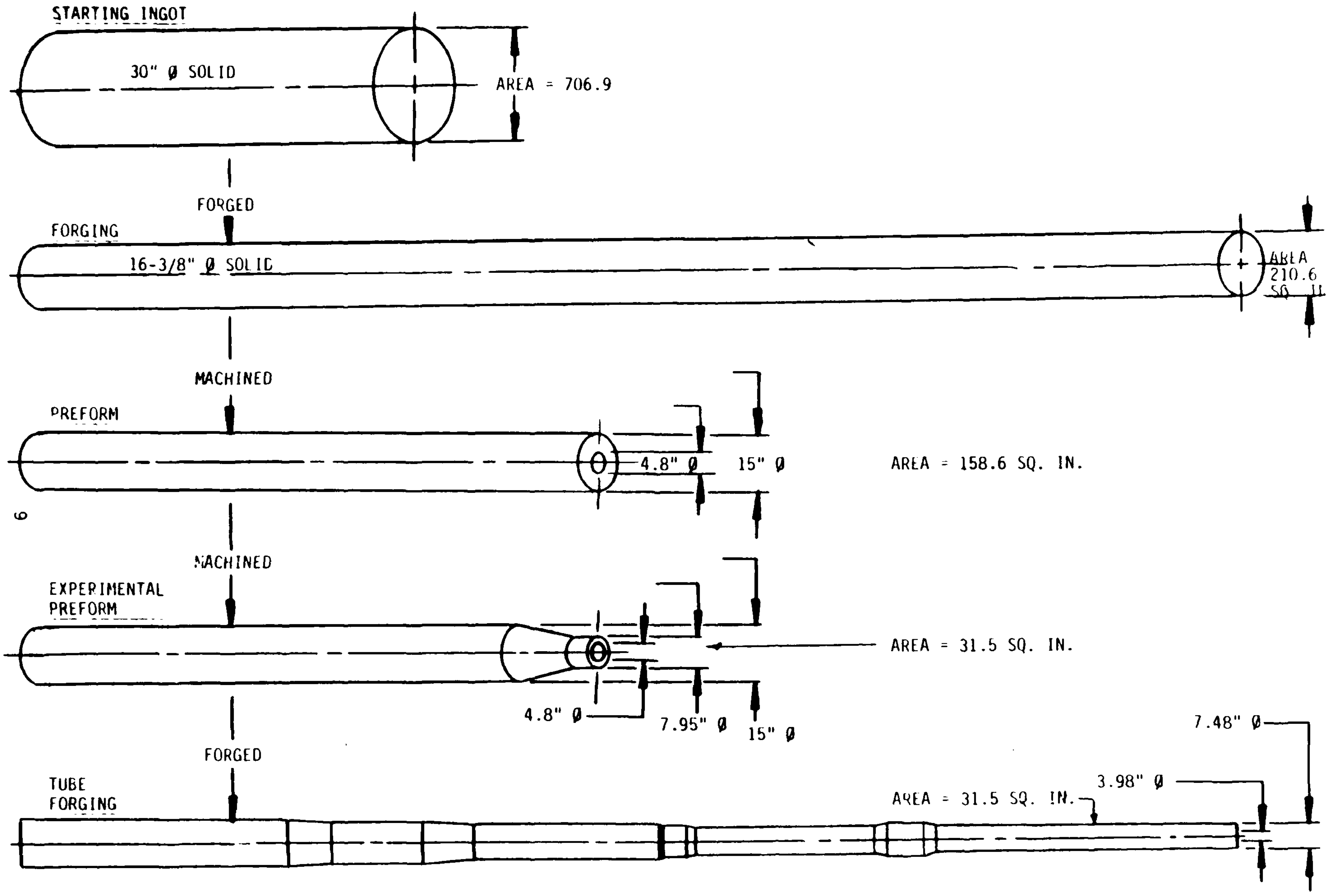

Figure 1. Material processing.

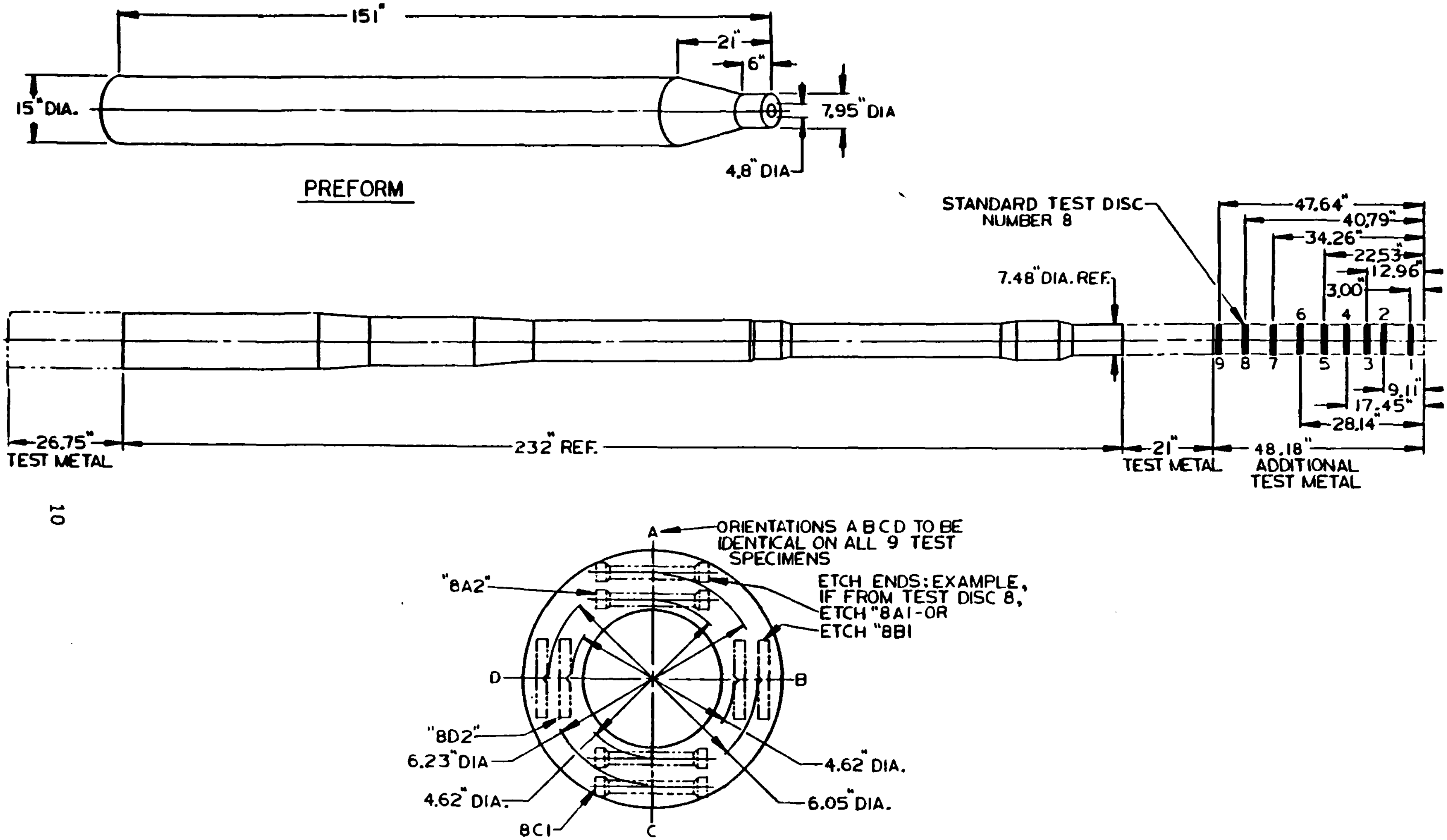

Figure 2. Layout for cutting test discs and test specimens.

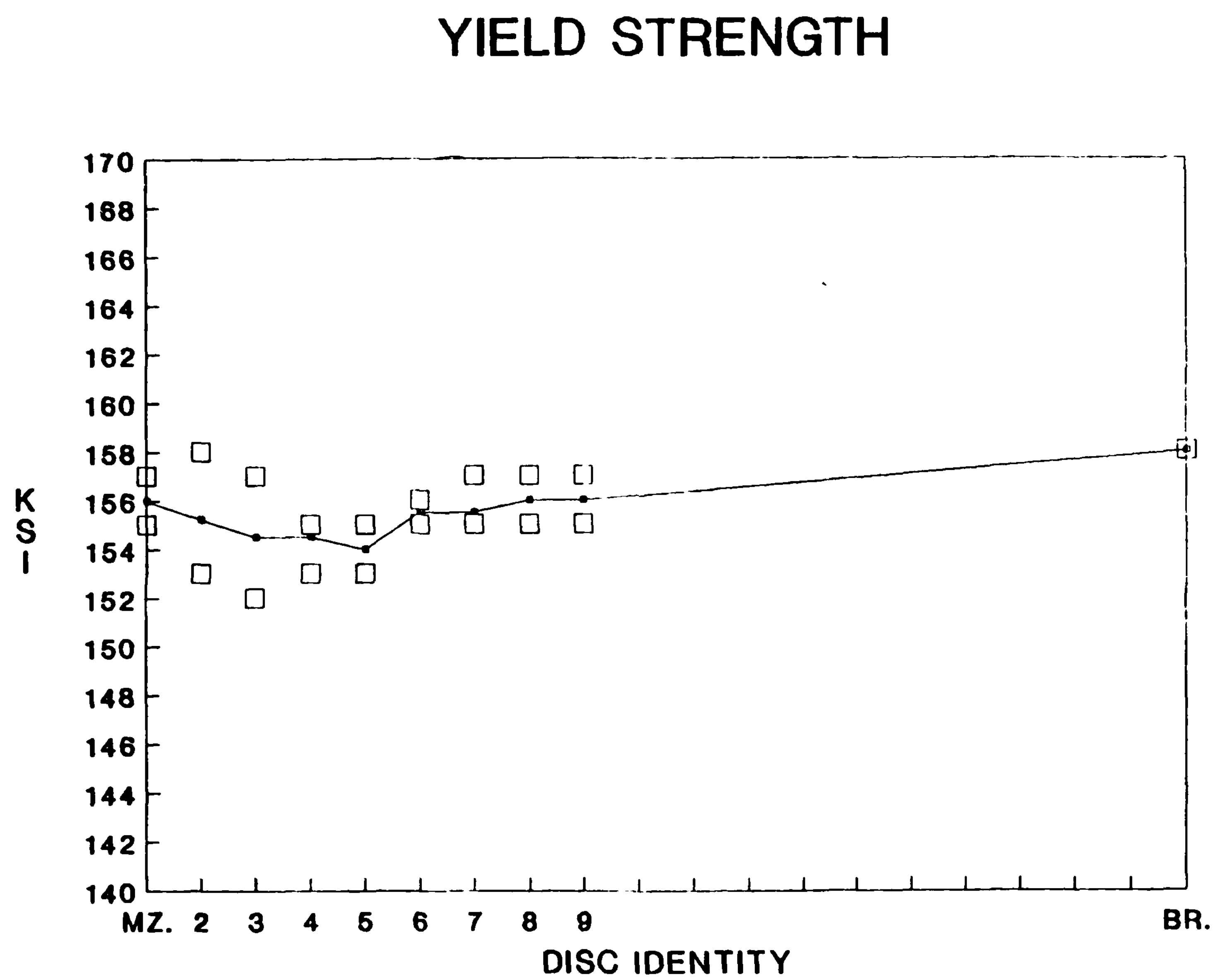

Figure 3. Yield strength versus location in tube.

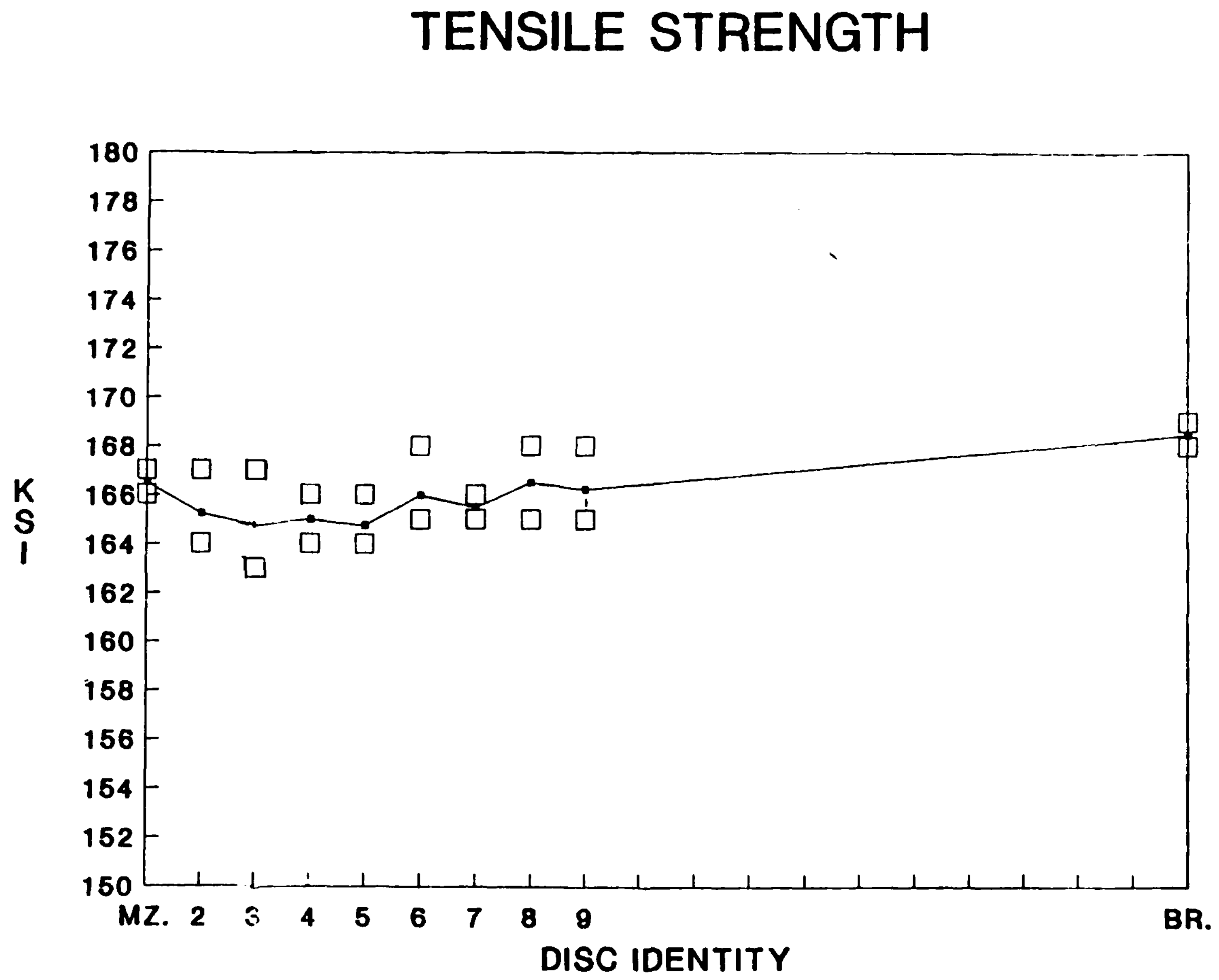

Figure 4. Tensile strength versus location in tube.

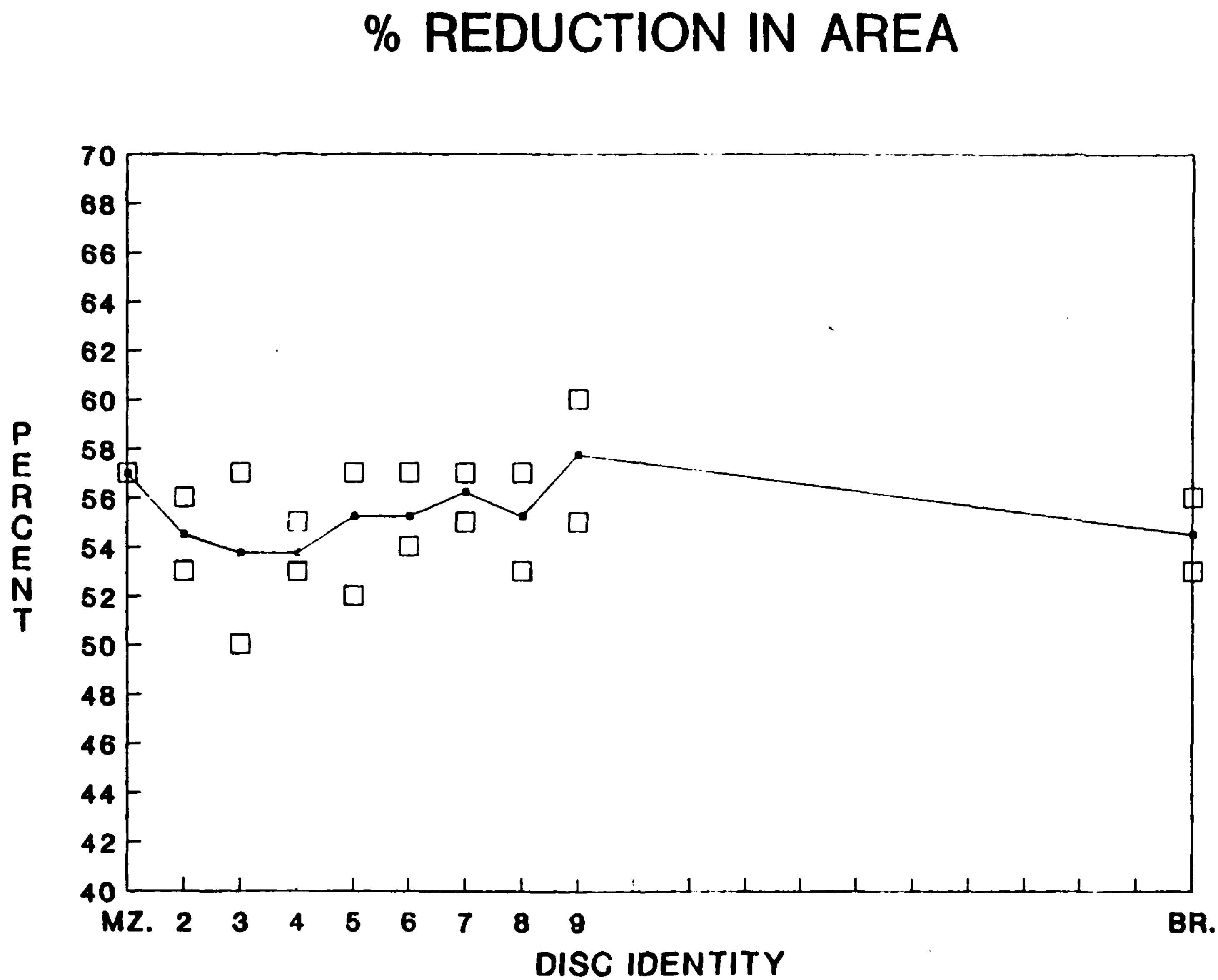

FIGURE 5

Figure 5. Percent reduction in area versus location in tube.

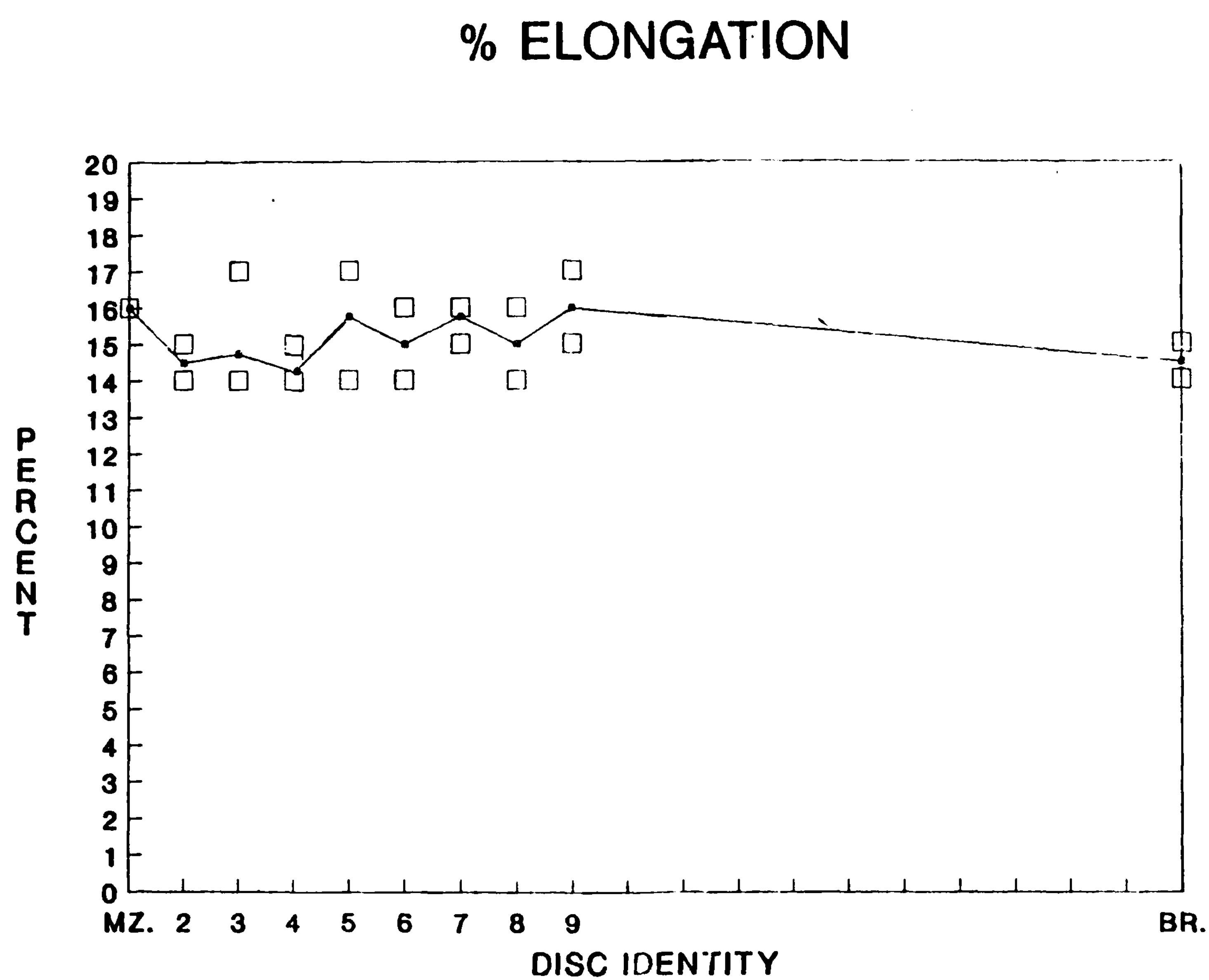

FIGURE 6

Figure 6. Percent elongation versus location in tube.

CHARPY IMPACT

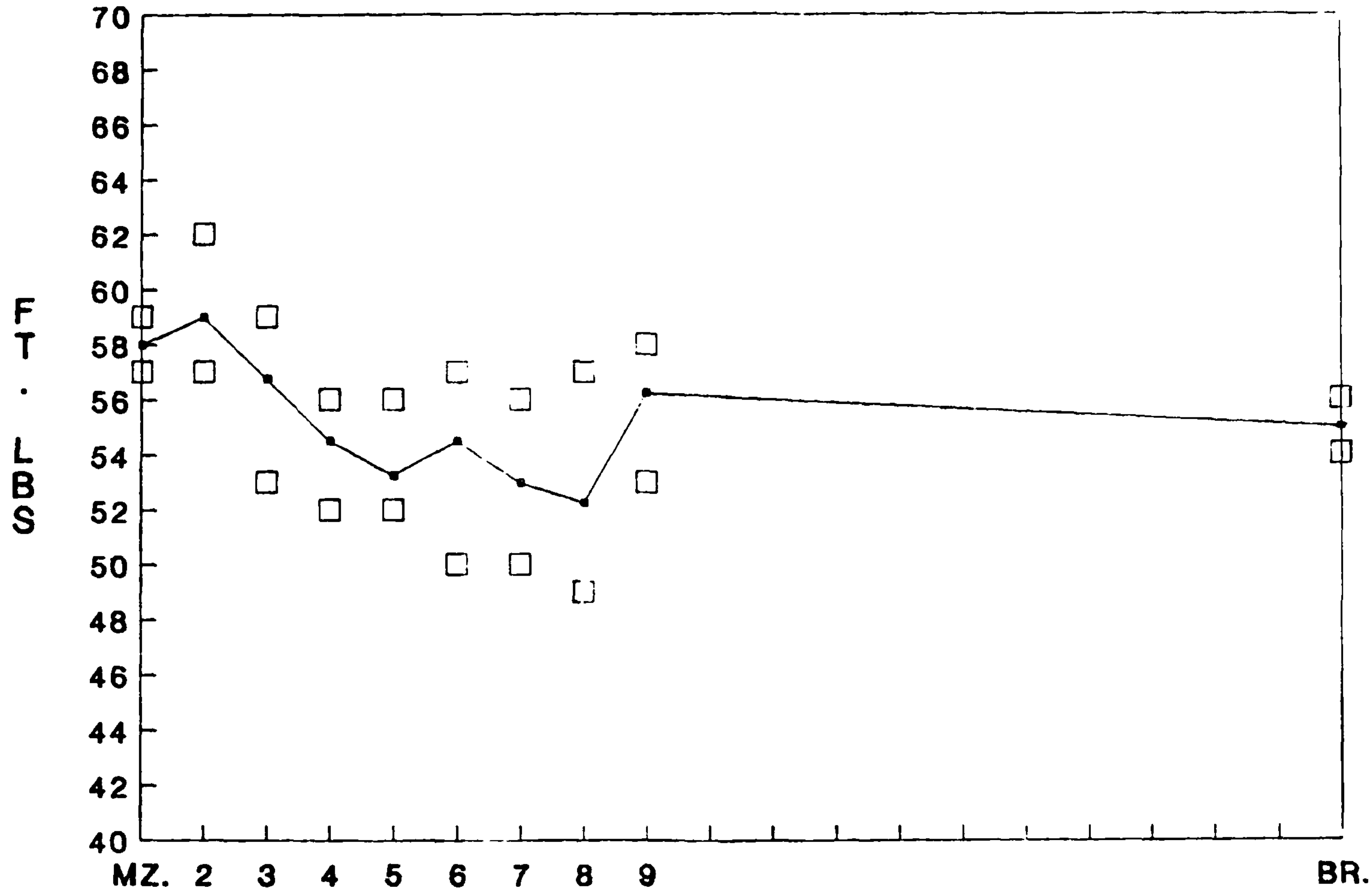

FIGURE 7

Figure 7. Charpy impact versus location in tube.

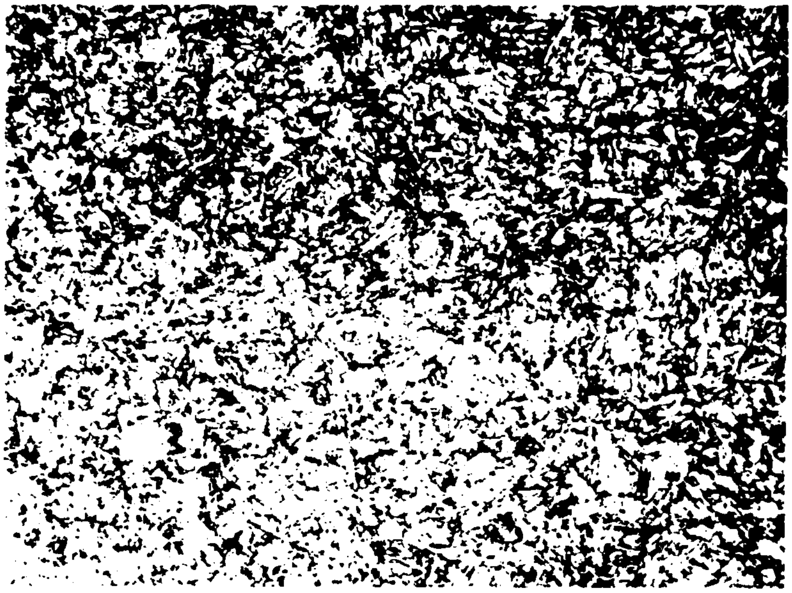

Figure 8. Photomicrograph depicting tempered martensitic microstructure found in all samples (400X, 2 percent nital).

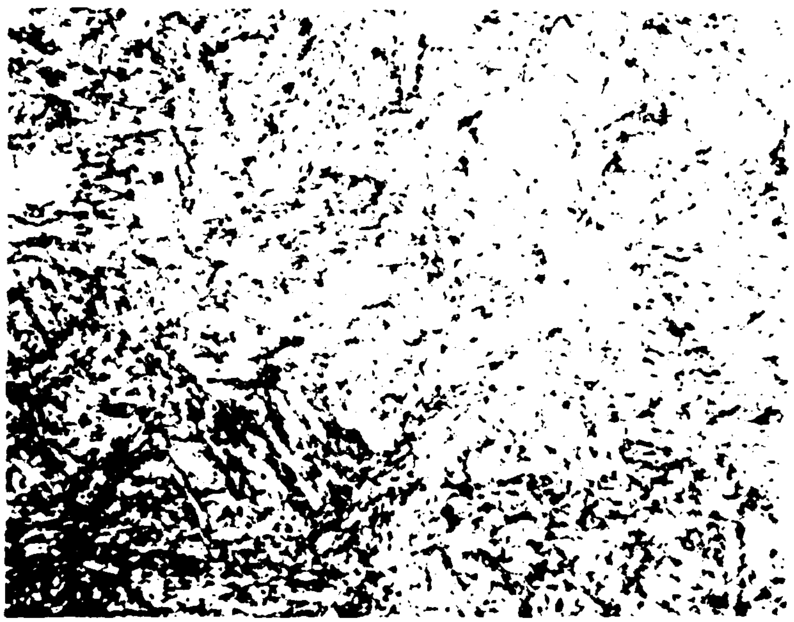

Figure 9. High magnification photomicrograph of tempered martensite (1000X, 2 percent nital).

(a) Disc #2

(b) Disc #9

Figure 10. Photomicrographs of macroetched structure found in mechanical property samples (50X, 1 percent picric).

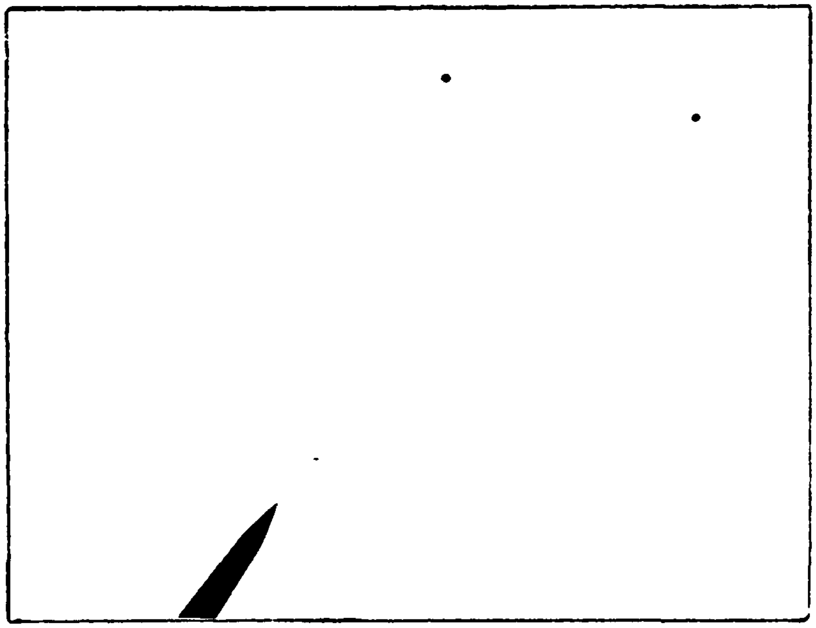

Figure 11. Typical oxide-type inclusions (dark spheres) found in all samples. The arrow points to a silicate-type stringer inclusion (100X).

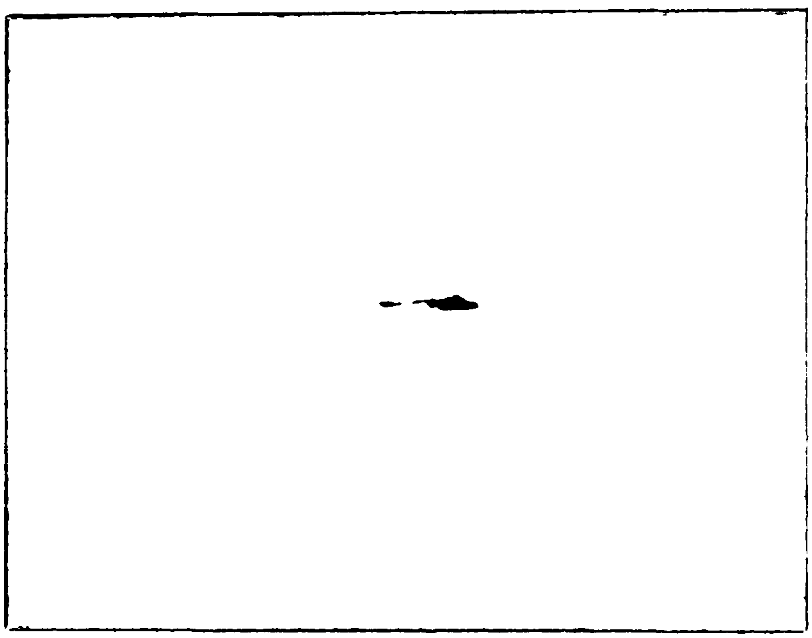

Figure 12. Higher magnification photomicrograph of "worst" stringer-type inclusion found in the subject material (400X).

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